Reply to Grinsted et al.: Estimating land subsidence in North Carolina

Reconstructions and observations of relative sea level (RSL) must be corrected for vertical land movements from glacial isostatic adjustment (GIA) to facilitate comparisons among regions and identify deviations from background rates. Late Holocene (past 2 ka) GIA rates are estimated from geological data and permanent global positioning system (GPS) stations or predicted from GIA models. We used a linear trend fitted to the regional, compaction-free, RSL reconstructions compiled by Engelhart et al. (1) for the past 2 ka (excluding data since AD 1900) as a GIA estimate. Similarly, GIA models also attribute all RSL changes during the past 2 ka to linear GIA and have zero eustatic (e.g., meltwater) contribution.

Grinsted et al. (2) contend that the approximately 1 mm/y GIA correction we applied to North Carolina (NC) RSL reconstructions (3) was too small, but their arguments are ill-founded and also misrepresent published results from Engelhart et al. (1, 4) that were co-authored by Horton and Peltier.

i) Peltier's GIA model ICE-5G VM2 predicts subsidence of approximately 1.3 mm/y for NC during the past 2 ka (2). However, this model does not fit Holocene RSL reconstructions from the US mid-Atlantic coast and systematically overpredicts subsidence rates because of mantle lateral heterogeneity and/or tectonic effects (4). Geological data implicitly account for these factors.

ii) Grinsted et al. (2) assert from the work of Engelhart et al. (1) that GPS observations indicate a greater rate of subsidence in NC than ICE-5G. The paper does not state this, and no NC measurements were reported (1). Rather, it concluded that GPS uncertainties are currently too large to confidently identify regional trends on the US mid-Atlantic coast because of the shortness of the time series. The nearest reported trend (Charleston, SC) was 1.6 ± 1.7 mm/y (5). GPS observations are the net effect of complex processes from which GIA must be isolated.

iii) Grinsted et al. (2) wrongly claim that a 4-mm/y sea-level rise from NC tide-gauge data was identified by Engelhart et al. (1). No NC tide gauges were used in that study. NC gauges at Oregon Inlet, Cape Hatteras, and Beaufort record rates of 2.55 to 3.46 mm/y (with uncertainty up to ±1.1 mm/y). Our reconstruction of RSL from NC was consistent with regional tide-gauge measurements (3). The same GIA rate applied to both datasets, so consistency was necessarily preserved. Following GIA correction (~1 mm/y), the NC reconstruction was also consistent with global tide-gauge compilations (3).

iv) The larger GIA correction (1.3 ± 0.5 mm/y) proposed by Grinsted et al. (2) accumulates to as much as 1.6 m over 2 ka (being up to 0.8 mm/y greater than ours). To reconcile this GIA rate with the thickness and age of salt-marsh peat on the US Atlantic coast (1, 4) requires eustatic sea-level fall of the same magnitude (2). This contradicts IPCC AR4 and the archeological data used by Grinsted et al. (6).

We applied a GIA rate of 1 mm/y and showed the effect of a ±0.15 mm/y range (3), which adequately spanned the uncertainty of estimating GIA for NC using geological data. Agreement with the semiempirical model described in our original publication (3) was independent of the chosen GIA correction, as the model can absorb any rate of linear trend.

Regional geological data remain the most robust means to estimate late Holocene GIA for regions along the US mid-Atlantic coast (including NC) that are affected by collapse of the glacial forebulge. The correction we applied is appropriate and therefore our conclusions remain unchanged.

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Author contributions: A.C.K., B.P.H., J.P.D., M.E.M., M.V., and S.R. wrote the paper.

The authors declare no conflict of interest.

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